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ALGORITHMS FOR GENERATING A SKEW-T, LOG P DIAGRAM AND COMPUTING SELECTED METEOROLOGICAL QUANTITIES

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Army Electronics Command
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By

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13. ABSTRACT
This paper discusses numerical methods of computing meteorological quantities which are usually manually derived from analysis on a SKEW-T, log p DIAGRAM. The numerical methods used were selected for their simplicity and accuracy. A mathematical characterization of the SKEW-T and algorithms for computing several meteorological quantities are presented.

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2. Numerical Methods						
3. Algorithms						
4. Data Reduction						

CONTENTS

SYMBOLS

CCL - Convective condensation level

Cp - Heat capacity of air at constant pressure

CT - Convective temperature

E - Actual vapor pressure

ES - Saturation vapor pressure

FR - Relative humidity

i,j,k - indexes

L - Latent heat of vaporization of water

LCL - Lifting condensation level

M - Saturation vapor pressure over water

P - Pressure

P* - Pressure correction

PB - Pressure at the bottom of a layer

PC - Pressure at the convective condensation level

PI - Pressure at the intersection

PM - Pressure at the top of the mixing layer

PS - Surface pressure

PT - Pressure at the top of a layer

R - Gas constant

T - Temperature

T* - Temperature correction

TD - Dewpoint temperature

TDS - Dewpoint temperature at the surface

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T_{DA} - Temperature on a dry adiabatic curve

TE - Psuedo equivalent temperature

TI - Temperature at an intersection

T_M - Temperature at the top of the mixing layer

T_{MR} - Temperature on a mixing ratio curve

T_{SA} - Temperature on a saturation adiabat curve

TW - Wet bulb temperature

W - Mixing ratio

$\overline{W}$ - Mean mixing ratio

X - Coordinate

Y - Coordinate

Z - Thickness of a layer

θ - Potential temperature

θE - Equivalent potential temperature

θ_S - Parameter for saturation adiabat

INTRODUCTION

The increasing availability of computing facilities, programmable calculators, and minicomputers allows many of the computations currently performed by manual graphics to be done by computer. This paper discusses numerical methods of computing meteorological quantities which are usually manually derived from analysis on a SKEW-T, log p DIAGRAM (or SKEW-T). The numerical methods used were selected for their simplicity and accuracy. A mathematical characterization of the SKEW-T and algorithms for computing several meteorological quantities are presented. Finally, a discussion of the application of these methods and a FORTRAN program listing to accomplish the computations are included.

THE SKEW-T, log p DIAGRAM

The SKEW-T, log p DIAGRAM [1] is a thermodynamic chart with five families of curves, five types of scales, and three data blocks. Various numerical information is also tabulated on the SKEW-T. This paper is concerned chiefly with the five families of curves which are associated with pressure, temperature, dry adiabat, saturation adiabat, and mixing ratio.

The first two families of curves, temperature and pressure, are used to locate points on the chart. An arbitrary coordinate system has been selected to measure distances. Let the origin correspond to the point at a temperature of 0C (centigrade) and a pressure of 1000 mb (millibars). Take the X direction to be parallel to the pressure lines (horizontal), with positive X to the right. The point at a temperature of 1C and a pressure of 1000 mb is on the positive side of the origin. The Y direction is perpendicular to the X direction. Positive Y is towards lower pressures (up). A point on the chart which is specified by its temperature and pressure may be transformed to X,Y coordinates by Eqs. (1) and (2). The components in the X,Y coordinate system are given in inches.†

$$X = .1408T - 10.53975 \log_{10} P + 31.61923 \tag{1}$$

$$Y = -11.5 \log_{10} P + 34.5 \tag{2}$$

†The X,Y coordinates have been scaled to USAF SKEW-T, log p DIAGRAM DOD-WPC-9-16-1. See [1].

The remaining three families of curves, TMR, TSA, and TDA, are given in Table 1. The temperatures are specified as a function of pressure and a parameter, the parameter serving as a means of specifying a particular curve of the family.

The temperature T at an arbitrary pressure on a saturation adiabat is determined by the bisection method.‡ The temperature is assumed to lie in the range -80C to 40C. An initial guess of -20C is made and the correction, T*, computed. The correction term decreases by a factor of 1/2 after each correction. Terminating after 13 corrections gave satisfactory results. The algorithm for computing the temperature on a saturation adiabat is based on Eq. (3):

$$\theta = (\theta E) \cdot EXP(- \frac{L \cdot W}{Cp \cdot T}) \tag{3}$$

The latent heat of vaporization L and the heat capacity of air at constant pressure Cp, are considered constant. Since it is not known how accurately the saturation adiabat could be determined from Eq. (3), Table 2 was constructed using List [2] as a standard. The temperature on an arbitrary mixing ratio curve W is computed by first computing the saturation vapor pressure M. An approximation to the inverse saturation vapor pressure function is then used to compute the temperature.

In addition to the algorithms which generate the curves for each family, it is necessary to have algorithms which determine which curve in a family passes through an arbitrary point (T,P). Algorithms to accomplish this are given in Table 3.

‡The bisection method is a numerical technique which decreases the difference between the upper and lower estimates by a factor of 1/2 per iteration.

TABLE I

SKEW-T ALGORITHMS

FAMILY	PARAMETER	ALGORITHM
Dry Adiabat	θ potential temperature	$T_{DA}(\theta,P) = \theta(\frac{P}{1000})^{.286}$
		T is in Kelvin. K=C + 273.16
Mixing Ratio	W mixing ratio	$T_{MR}(W,P) = 10^{(a\log_{10}m + b)} + c + d(m^f + g)^2$
		a = .0498646455
		b = 2.4082965
		c = 280.23475
		d = 38.9114
		f = .0915
		g = -1.2035
		$m = \frac{W*P}{(622 + W)}$

TABLE I (con.)

FAMILY	PARAMETER	ALGORITHM
Saturation Adiabat	θ_S the temperature at 1000 mb	$T_{SA}(\theta_S,P) = T_1 + \sum_{i=1}^{12} T_i^*$ $T_1 = 253.16$ K $T_i^* = \frac{120}{2^i}\ \mathrm{SIGN}\left[a\ \mathrm{EXP}\left\{\frac{bW(T_i,P)}{T_i}\right\} - T_i \left(\frac{1000}{P}\right)^{.288}\right]$ $T_i = T_{i-1} + T_{i-1}^*$ $a = \theta_S$ $b = -2.6518986$ $W(T,P) = \frac{622\ \mathrm{ESAT}\ (T)}{P - \mathrm{ESAT}\ (T)}$ ESAT (T) = 10.**(23.832241-5.02808*ALOG10(T)-1.3816E-7* 10.**(11.344-0.0303998*T)+8.1328E-3*10.** (3.49149-1302.8844/T)-2949.076/T) NOTE: T is in Kelvin. K = C + 273.16 ESAT is from Nordquist [3]. The SIGN function is -1 or +1 corresponding to the algebraic sign of the argument.

TABLE 2

TEMPERATURE AND ERROR ON SELECTED SATURATION ADIABATS AT SELECTED PRESSURES

Pressure (mb)	Temperature (C)	Error (C)
1000.0	40.0000	
701.5	29.9877	.0122
490.7	19.9536	.0463
344.7	9.9194	.0805
245.4	-.1733	-.1733
179.6	-10.2221	-.2221
1000.0	30.0000	
733.0	19.9829	.0170
544.0	9.9633	.0366
412.4	-.0561	-.0561
321.4	-10.0756	-.0756
257.7	-20.1538	-.1538
212.0	-30.2612	-.2612
177.6	-40.3247	-.3247
1000.0	20.0000	
770.0	9.9780	.0219
606.0	-.0561	-.0561
489.0	-10.0463	-.0463
403.0	-20.1245	-.1245
338.0	-30.1879	-.1879
286.4	-40.2368	-.2368
243.5	-50.2709	-.2709
206.8	-60.2612	-.2612
174.7	-70.2661	-.2661
1000.0	10.0000	
805.0	-.0415	-.0415
663.0	-9.9877	.0122
554.0	-20.0952	-.0952
470.0	-30.0268	-.0268
400.0	-40.1196	-.1196
341.0	-50.1538	-.1538
289.9	-60.1586	-.1586
245.1	-70.1489	-.1489
205.7	-80.1098	-.1098
171.0	-90.1147	-.1147

TABLE 2 (con.)

Pressure (mb)	Temperature (C)	Error (C)
1000.0	.0000	
833.0	-9.9731	.0268
703.0	-19.9926	.0073
599.0	-29.9829	.0170
511.0	-40.1196	-.1196
436.4	-50.1391	-.1391
371.3	-60.1293	-.1293
314.0	-70.1196	-.1196
263.5	-80.0952	-.0952
219.1	-90.0854	-.0854
1000.0	-10.0000	
849.0	-20.0073	-.0073
726.0	-29.9829	.0170
621.0	-40.0756	-.0756
531.2	-50.0512	-.0512
452.2	-60.0415	-.0415
382.4	-70.0463	-.0463
266.9	-89.9975	-.0024
1000.0	-20.0000	
856.8	-30.0122	-.0122
734.8	-40.0170	-.0170
628.6	-50.0366	-.0366
535.3	-60.0268	-.0268
452.8	-70.0170	-.0170
380.0	-80.0073	-.0073
316.0	-89.9829	.0170

TABLE 3

DETERMINING A CURVE THROUGH A GIVEN POINT

FAMILY	PARAMETER FOR CURVE PASSING THROUGH (T,P)
Dry Adiabat	$\theta = T(\frac{1000}{P})^{.288}$
Mixing Ratio	$W = \frac{622\ ESAT(T)}{P - ESAT(T)}$
Saturation Adiabat	$\theta_S = \frac{T(\frac{1000}{P})^{.288}}{EXP\ (\frac{bW(T,P)}{T})}$
	$b = -2.6518986$

NOTE: T is in Kelvin. K = C + 273.16 (see Table I for a definition of ESAT)

ALGORITHMS FOR SELECTED METEOROLOGICAL QUANTITIES

Several meteorological quantities which are usually manually derived from an analysis of a SKEW-T were selected for discussion. Algorithms are presented for computing these meteorological quantities. The selection of symbols is somewhat different than is customary because of current symbol limitations on computers. But by referring to the List of Symbols, the reader will have no difficulty. Units are the same as those used on the SKEW-T [1].

Mixing Ratio: W

The mixing ratio W is computed from the pressure P and the dewpoint temperature TD by using the function ESAT, which is defined in Table I.

$$W = \frac{622\ ESAT(TD)}{P - ESAT(TD)} \tag{4}$$

TD is in degrees Kelvin, the pressure P in millibars, and W in grams of water vapor per kilogram of dry air. The saturation mixing ratio is obtained by using the dry bulb temperature in place of the dewpoint temperature.

Relative Humidity: FR

The relative humidity is computed from the temperature T and the dewpoint temperature TD by using ESAT. Both T and TD are in degrees Kelvin.

$$FR = 100\ (ESAT(TD)/ESAT(T)) \tag{5}$$

Saturation Vapor Pressure: ES

ESAT gives the saturation vapor pressure in millibars from the dry bulb temperature T, which is in degrees Kelvin.

$$ES = ESAT(T) \tag{6}$$

Actual Vapor Pressure: E

The dewpoint temperature TD is used in place of T in Eq. (6).

Potential Temperature: θ

The potential temperature is computed from the dry bulb temperature T in Kelvin and the pressure P in millibars.

$$\theta = T \left(\frac{1000}{P}\right)^{.288} \tag{7}$$

The Wet Bulb Temperature and Wet Bulb Potential Temperature: TW,θW

The wet bulb temperature is approximated by calculating the psuedo wet bulb temperature. The arguments are surface dewpoint temperature, surface temperature, and pressure, which are symbolized by TDS, TS, and PS, respectively. TDS and TS are in Kelvin, P in millibars. First a mixing ratio curve W, which passes through (TDS, PS), is determined. From Table 3 we have:

$$W = \frac{622 \ \ ESAT\ (TDS)}{P - ESAT\ (TDS)} \tag{8}$$

Next a dry adiabat, which passes through (TS, PS), is determined. Again by referring to Table 3 we have:

$$\theta = TS\left(\frac{PS}{1000}\right)^{.288} \tag{9}$$

Two curves have now been specified: T_{MR} (W, P) and T_{DA} (θ, P). The next step is to locate the pressure at which the curves intersect. This is done by an iterative procedure. An initial guess that the intersection pressure PI is equal to the surface pressure is made. A correction is computed and a revised guess made. When $(T_{MR} - T_{DA})^2$ is loss than .0001 degrees, the process is terminated.

$$PI_i = PS \tag{10}$$

$$PI_i = PI_{i-1} + P^*_{i-1} \qquad (11)$$

$$P^*_k = P_k \, 2^{(.02(T_{MR}(W,P_k) - T_{DA}(\theta,P_k)))} \qquad (12)$$

It is found that six iterations were sufficient to compute PI to within 1 mb. Once the pressure and hence temperature at the intersection are known, a saturation adiabat through the intersection point (TI, PI) is found. Referring to Table 3 we have:

$$\theta_S = \frac{TI \quad (\frac{1000}{PI})^{.288}}{EXP\ (\frac{bW(TI,\ PI)}{TI})} \qquad (13)$$

Finally by following this saturation adiabat to the surface pressure PS and to 1000 mb, we get the wet bulb temperature TW and the wet bulb potential temperature θW, respectively.

$$TW = T_{SA}\ (\theta_S,\ PS) \qquad (14)$$

$$\theta W = T_{SA}\ (\theta_S,\ 1000) \qquad (15)$$

The Psuedo Wet Bulb Temperature and Pseudo Wet Bulb Potential Temperature: TPW, θPW

Refer to the wet bulb temperature and wet bulb potential temperature above.

The Equivalent Potential Temperature: θE

The equivalent potential temperature is computed from the same quantities used to compute the wet bulb temperature, i.e., the surface pressure, dewpoint temperature, and actual temperature. First compute the wet bulb temperature TW. The equivalent potential temperature can then be computed by the same process used to determine the parameter θ_S of a saturation adiabat through (TW, PS). Referring to Table 3 we have:

$$\theta E = \frac{TW \left(\frac{1000}{PS}\right)^{.288}}{EXP\left(\frac{bW(TW,\ PS)}{TW}\right)} \tag{16}$$

The Psuedo Equivalent Temperature: TE

First the equivalent potential temperature θE is computed. The psuedo equivalent temperature is then given by

$$TE = \theta E \left(\frac{PS}{1000}\right)^{.288} \tag{17}$$

Thickness of a Layer: Z

It is assumed that the temperature and dewpoint temperature are known at N distinct, decreasing pressures. Thicknesses are computed in meters from the surface. The trapezoidal rule is used to integrate

$$Z = \frac{R}{.98} \int_{\ln PS}^{\ln PT} [T + .6078{*}W{*}T/(1000 + W)]d \ln P \tag{18}$$

See Table I for a definition of W(T, P).

Rewriting Eq. (18) and noting that W<<1000 gives Eq. (19), which is used to perform the computation of Z:

$$Z = 29.2857 \left[\frac{(T_1 + T_2 + 6.078 \cdot 10^{-6} \cdot (W_1 \cdot T_1 + W_2 \cdot T_2))}{2} \cdot \ln(P_1/P_2) \right.$$

$$+ \frac{(T_2 + T_3 + 6.078 \cdot 10^{-6} \cdot (W_2 \cdot T_2 + W_3 \cdot T_3))}{2} \cdot \ln(P_2/P_3)$$

$$\left. + \ldots + \frac{(T_n + T_{n+1} + 6.078 \cdot 10^{-6} \cdot (W_n \cdot T_n + W_{n+1} \cdot T_{n+1}))}{2} \cdot \ln(P_n/P_{n+1}) \right] \tag{19}$$

The Lifting Condensation Level: LCL

The lifting condensation level is computed in the same manner that Pl was computed for the wet bulb temperature. Eqs. (8), (9), (10), (11), and (12) are used. (Tl, Pl) locate the LCL.

The Convective Condensation Level: CCL

It is assumed that the temperature and dewpoint temperature are known at N distinct, decreasing pressures. The pressure at the top of the mixing layer PM must be greater than P_n, the last pressure level. Since PM is bounded by P_1 and P_n, there is a K such that

$$P_k > PM \geq P_{k+1} \tag{20}$$

First the mean mixing ratio, $\overline{W}$, in the P_1 - PM layer is computed:

$$\overline{W} = \frac{\sum_{i=1}^{k-1} \left[W(T_i, P_i) + W(T_{i+1}, P_{i+1})\right] (\ln P_i - \ln P_{i+1})}{2(\ln P_1 - \ln PM)}$$

$$+ \frac{\left[W(T_k, P_k) + W(T_m, PM)\right] (\ln P_k - \ln PM)}{2(\ln P_1 - \ln PM)} \tag{21}$$

The intersection of T_{MR} ($\overline{W}$, P) and the curve defined by

$$T_S (P) = T_k - \frac{(T_{k+1} - T_k)(\ln P - \ln P_k)}{(\ln P_k - \ln P_{k+1})} \tag{22}$$

(k is chosen such that $P_k > P \geq P_{k+1}$) defines the convective condensation level. This intersection can be found by first systematically comparing the difference between $T_{MR}(\overline{W}, P_i)$ and $T_S(P_i)$ until the smallest i is found, such that

$$T_{MR}(\overline{W}, P_i) - T_S(P_i) < 0 \qquad (23)$$

and

$$T_{MR}(\overline{W}, P_{i+1}) - T_S(P_{i+1}) > 0 \qquad (24)$$

A bisection method is used to determine PC, the pressure at the CCL. An initial guess PC_1 is made, tested to see if $T_{MR}(\overline{W}, PC_1)$ equals $T_S(PC_1)$, and if not, corrected.

$$PC_1 = .5\,(P_i + P_{i+1}) \qquad (25)$$

$$PC_j = PC_{j-1} + P^*_{j-1} \text{ (corrector)} \qquad (26)$$

$$P^*_k = \frac{(P_i + P_{i+1})}{2^k} \text{ SIGN } (T_{MR}(\overline{W}, PC_k) - T_S(P_k)) \qquad (27)$$

Ten corrections are made.

The Convective Temperature: CT

First the pressure PC at the convective condensation level is computed. The temperature at the CCL, TC, is computed from PC and $\overline{W}$:

$$TC = T_{MR}(\overline{W}, PC) \qquad (28)$$

A dry adiabat is determined.

$$\theta = TC \left(\frac{1000}{PC}\right)^{.288} \tag{29}$$

Finally, the convective temperature CT is computed from θ and the surface pressure PS:

$$CT = \theta \left(\frac{PS}{1000}\right)^{.288} \tag{30}$$

APPLICATIONS

The algorithms are useful for data reduction purposes. The memory and speed requirements are not excessive and most computations can be carried out satisfactorily on a programmable calculator. In addition to data analysis, the algorithms are useful for generating backgrounds for the presentation of data. An example of a computer generated background and plotted sounding is given in Fig. 1. Computation of selected meteorological quantities from the sounding in Fig. 1 are presented in Table 4. A table of CCL temperatures, pressures, and heights was computed using an arbitrary decrement of -25 mb for the pressure at the top of the mixing ratio.

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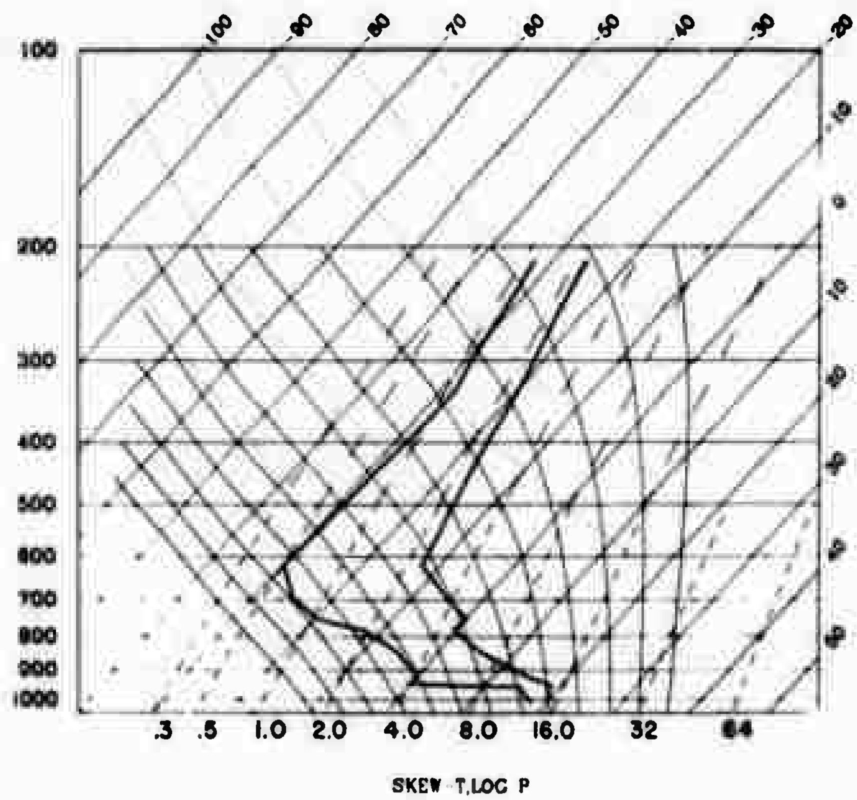

Figure 1. A computer-generated SKEW-T background with a hypothetical profile of temperature and dewpoint temperature. Horizontal lines are pressure. Positive sloped lines are temperature (solid) and mixing ratio (dashed). Negative sloped curves are dry adiabat (dashed) and saturated adiabat (solid).

TABLE 4

AN EXAMPLE OF A VERTICAL SOUNDING

Press.	1013	953	950	942	920	843	777	745	691	620	333	210
Height	0	536	554	626	827	1553	2213	2549	3145	3984	8664	12047
Pot. T.	19.3	22.3	23.3	23.2	21.3	19.8	19.8	24.0	24.5	26.2	74.1	115.0
Temp.	20.4	18.2	19.0	18.2	14.4	5.8	-0.7	-0.1	-5.5	-12.3	-20.1	-25.5
Dew pt.	18.2	14.4	6.0	-0.8	-0.6	-5.2	-12.7	-20.1	-25.5	-30.3	-28.1	-32.5
R.H.	87	79	43	28	36	45	40	21	19	21	49	52
Mix Ratio	13.1	10.9	6.09	3.86	4.10	3.01	1.91	1.04	.70	.51	1.14	1.17
Sat. V.P.	24.0	20.9	22.0	20.9	16.4	9.2	5.8	6.0	4.1	2.4	1.2	0.8
V. Press.	20.9	16.4	9.2	5.8	6.0	4.1	2.4	1.2	0.8	0.5	0.6	0.4
W. Bulb Temp	19.0	15.9	11.7	8.8	7.1	1.2	-4.7	-5.9	-10.2	-15.7	-22.1	-27.4
Pot. W.B. Temp	18.5	17.8	13.7	11.4	10.9	9.0	7.7	8.4	8.2	8.7	23.9	31.1
Equiv. Pot. Temp	56.7	54.2	41.3	34.8	33.5	28.9	25.8	27.3	26.9	28.0	78.6	120.3

LCL at Temp. 17.9 Press. 983 Height 260

Mixing Layer		CCL		Convective Temp	Mean Mixing Ratio
Press	Height	Press	Height		
988	215	931	725	23.4	12.64
963	437	928	757	23.1	12.19
938	662	911	908	22.3	10.68
913	890	882	1173	21.8	8.95
888	1121	863	1361	21.4	7.86
863	1359	847	1511	21.1	7.08
838	1602	832	1660	21.0	6.47
813	1846	817	1807	21.0	5.95
788	2099	803	1942	21.0	5.50
763	2358	790	2075	21.0	5.08

Units: temperature C; pressure millibar; mixing ratio grams/kilogram; height meters.

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APPENDIX A

PROGRAM LISTING

```
C
C
C
CTHERMODYNAMIC CHART SOFTWARE PACKAGE
C
CTHE FOLLOWING SUBROUTINES APPROXIMATE A THERMODYNAMIC CHART
CT IS TEMPERATURE IN KELVIN.  SCALAR IN ALL FUN EXCEPT Z AND CCL
CTD IS DEWPOINT TEMP                        DITTO
CP IS PRESSURE IN MILLIBARS                DITTO
CTDS,TS,PS ARE TD,T,P AT SURFACE
CWBAR IS THE MEAN MIXING RATIO
CO IS REALLY A THETA
CSOUNDINGS MUST BE ORDERED BY DECREASING PRESSURE
CFR(T,TD) RELATIVE HUMIDITY
CTW(TDS,TS,PS) WET BULB TEMP
COW(TDS,TS,PS) IS POTENTIAL WET BULB
COE(TDS,TS,PS) IS POTENTIAL EQUIVALENT/PSEUDO EQUIVALENT TEMP
CTE(TDS,TS,PS) IS EQUIV TEMP
CALCL(TDS,TS,PS) IS THE PRESSURE AT THE LCL
CCCL(PM,P,T,TD,WBAR,N) IS THE PRESSURE AT THE CCL
CPM  INPUT PRESS AT TOP OF MIXING LAYER
CN  IS NO OF LEVELS IN SOUNDING
CCT (WBAR,PC,PS)    CONVECTIVE TEMP
CPC IS PRESSURE AT CCL
CZ(PT,P,T,TD,N)   THICKNESS IN METERS FROM P(1) TO PT
CXX(T,P)     X,Y COORDINATES OF T,P ON SKEWT IN INCHES
CYY(P)      DITTO
CTDA(O,P)  TEMP ON DRY ADIABAT O AT LEVEL P
CTMR(W,P) TEMP ON MIXING RATIO W AT LEVEL P
CTSA (OS,P) TEMP ON SATURATED ADIABAT OS AT LEVEL P
CESAT(T)  SATURATION VAPOR PRESSURE OVER WATER AT TEMP T
CW(T,P) THE MIXING RATIO LINE THROUGH T,P
CO(T,P) THE DRY ADIABAT THROUGH T,P
COS(T,P) THE SAT ADIABAT THROUGH T,P
C
```

```
C
C
C
C
      FUNCTION  FR(T,TD )
C    FR (PER CENT ), T AND TD (KELVIN)
      FR  =  100.*( ESAT(TD)/ESAT(T) )
      RETURN
      END
C
C
C
C
C
      FUNCTION  TW( TDS,TS,PS )
C     ABS IS ABSOLUTE VALUE
C     ALL ARGUMENTS AND TW (KELVIN)
      AW = W(TDS,PS)
      AO = O(TS,PS)
      PI =  PS
      DO  4  I =1,10
      X  =  .02*( THR(AW,PI) - TDA(AO,PI) )
      IF ( ABS(X).LT. 0.01  )  GO TO  5
    4 PI = PI* ( 2.**(X)  )
    5 TI  =  TDA(AO,PI)   +273.16
C    THE INTERSECTION POINT HAS BEEN FOUND, NOW FIND A SAT-ADIABAT THRU
C    IT.
      AOS  =   OS(TI,PI)
      TW   =  TSA( AOS,PS)
     RETURN
      END
C
C
C
C
```

```
PAGE  3     SKEW-T PROGRAM ROUTINES

C
      FUNCTION   OW(TDS,TS,PS)                                          18
C     ALL ARGUMENTS AND OS (KELVIN)
         ATW = TW(TDS,TS,PS)    +273.16                                 19
         AOS = OS(ATW,PS)                                               20
         OW  = TSA(AOS,1000.)                                           21
      RETURN                                                            22
         END                                                            23
C
C
C
C
C
         FUNCTION  OE(TDS,TS,PS)                                        24
C     ALL ARGUMENTS AND OE  (KELVIN)
         ATW  =  TW(TDS,TS,PS )  +273.16                                25
         OE   =  OS(ATW,1000.)      -273.16                             26
      RETURN                                                            27
         END                                                            28
C
C
C
C
C
         FUNCTION   TE(TDS,TS,PS)                                       29
C     ALL ARGUMENTS AND TE  (KELVIN)
         AOE =  OE(TDS,TS,PS)       +273.16                             30
         TE  =  TDA(AOE,PS)                                             31
      RETURN                                                            32
         END                                                            33
C
C
C
C
C
```

```
PAGE  4     SKEW-T PROGRAM ROUTINES

      FUNCTION   ALCL(TDS,TS,PS)
C      ABS IS ABSOLUTE VALUE
C      ALL ARGUMENTS AND TW (KELVIN)
        AW = W(TDS,PS)
        AO = O(TS,PS)
        PI =  PS
        DO  4  I =1,10
        X  =  .02*( TMR(AW,PI) - TDA(AO,PI) )
        IF ( ABS(X).LT. 0.01  )  GO TO  5
    4   PI = PI* ( 2.**(X)  )
    5 ALCL =  PI
      RETURN
        END
C
C
C
C
C
        FUNCTION CCL(PM,P,T,TD,WBAR,N)
C     N IS NO. OF LEVELS IN SOUNDING. K IS THE LAST LEVEL BELOW PM.
C     CCL AND P (MILLIBAR) ,T,K (KELVIN) , WBAR (GRAMS VAPOR/KILOGRM DRY
C     AIR.)
        DIMENSION T( N),P( N),TD( N)
        WBAR =0
        K=0
  200       K=K+1
        IF( P(K)-PM)  201,201,200
  201    CONTINUE
        K=K-1
        J=K-1
             IF(J.LT.1) GO TO 101
C     COMPUTE THE  AVERAGE MIXING RATIO. ALOG IS LOG BASE E
             DO  100 I=1,J
                 L=I+1
  100   WBAR=(W(TD(I),P(I))+W(TD(L),P(L)))*ALOG(P(I)/P(L))+WBAR
```

```
 101      CONTINUE
                L=K+1
      TQ=TD(K)+(TD(L)-TD(K)   )*(ALOG(PM/P(K)))/(ALOG(P(L)/P(K)))
          WBAR = (WBAR+(W(TD(K),P(K))+W(TQ    ,PM   ))*ALOG(P(K)/PM))
                WBAR=  WBAR/( 2.*ALOG(P(1)/PM) )
C     FIND THE  LEVEL AT WHICH  TMR -TS  CHANGES  SIGN.TS -SOUNDING
          DO 105 I=1,N
          X =  TMR(WBAR,P(I))  - T(I)  +273.16
          IF ( X.GE.0.0) GO TO  110
 105      CONTINUE
          CCL = 0.0
          RETURN
C         SET UP BISECTION ROUTINE
 110      L = I-1
          DEL = P(L)- P(I)
          PC  =  P(I) + .5*DEL
          A=    ( T(I)-T(L))/ALOG( P(L)/P(I))
          DO 120 J=1,10
          DEL = DEL/2.
          X  = TMR(WBAR,PC) -  T(L) - A*(ALOG(P(L)/PC ) )+273.16
C         THE  SIGN FUNCTION REPLACES THE SIGN OF THE FIRST ARGUMENT
C         WITH THE SECOND.
  120     PC = PC +      SIGN(DEL,X)
          CCL=PC
          RETURN
          END
C
C
C
C
C
      FUNCTION  CT(WBAR,PC,PS )
C     WBAR (GRAMS/KILOGRAM) , PC,PS (MILLIBAR)
          TC  =  TMR(WBAR,PC)        +273.16
          AO  =    O(TC,PC )
```

```
      CT  =  TDA(AO,PS)
   RETURN
      END
C
C
C
C
C
      FUNCTION   Z(PT,P,T,TD,N)
      DIMENSION T( N),P( N),TD( N)
      DIMENSION P(50),T(50),TD(50)
      Z = 0.0
      I =  0
 9       I = I+1
      J  = I+1
      IF(PT.GE.P(J)) GO TO 10
      A1 = T(J)*(1. + .0006078 * W(TD(J),P(J)))
       A2 = T(I)*(1. + .0006078*W(TD(I),F(I)))
      Z = Z+14.64285*(A1+A2)*(ALOG(P(I)/P(J)))
      GO TO 9
10    CONTINUE
      A1 = T(J)*(1. + .0006078*W(TD(J),P(J)))
       A2 = T(I)*(1. + .0006078*W(TD(I),P(I)))
      Z = Z+14.64285*(A1+A2)*(ALOG(P(I)/PT ))
      RETURN
   END
C
C
C
C
C
      FUNCTION XX(TK,P)
      T=TK-273,16
     XX = .1408*T -10.53975*ALOG10(P) +31.61923
   RETURN
```

```
         END                                                     108
C
C
C
C
C
      FUNCTION YY(P)                                             109
C     ALOG10 IS LOG TO THE BASE TEN. P(MILLIBARS),T(KELVIN),X(INCHES)
         YY =   -11.5*ALOG10(P)  + 34.5                          110
      RETURN                                                     111
         END                                                     112
C
C
C
C
C
      FUNCTION  TDA(O,P)                                         113
C     TDA(KELVIN),O(KELVIN),P(MILLIBAR)
      TDA =  O*(  (P/1000.)**.288 )     -273.16                  114
      RETURN                                                     115
         END                                                     116
C
C
C
C
C
      FUNCTION  TMR(W,P)                                         117
C     TMR(KELVIN),W(GRAMS WATER VAPOR/KILOGRAM DRY AIR),P(MILLIBAR)
C     ALOG10  IS   LOG TO THE BASE  TEN.
      X =  ALOG10(   W*P/(622.+ W)   )                           118
      TMR=10.**(.0498646455*X+2.4082965)-280.23475+38.9114*((10.**(   119
     1  .0915*X ) - 1.2035 )**2 )                                120
      RETURN                                                     121
         END                                                     122
C
```

```
C
C
C
C
      FUNCTION TSA(OS,P)
C     TSA AND OS(KELVIN),P(MILLIBARS)
C     SIGN(A,B) RREPLACES THE ALGEBRETIC SIGN OF A WITH THE SIGN OF B
      A  =  OS
        TQ  =  253.16
      D =  120
      DO 1  I = 1,12
      D = D/2.
C     IF THE TEMPERATURE DIFFERENCE,X, IS SMALL,EXIT THIS LOOP
      X = A*EXP(-2.6518986*W(TQ,P)/TQ)-TQ*((1000./P)**.288)
      IF( ABS(X)  .LT.  1.0E-7)  GO TO 2
      TQ = TQ + SIGN(D,X)
 1    CONTINUE
 2    TSA = TQ-273.16
      RETURN
      END
C
C
C
C
C
      FUNCTION  ESAT(T)
C     ESAT(MILLIBARS),T(KELVIN)
          ESAT     = 10.**(23.832241-5.02808*ALOG10(T)-1.3816E-7*
     1               10.**(11.344-0.0303998*T)+8.1328E-3*10.**
     2               (3.49149-1302.8844/T)-2949.076/T)
      RETURN
      END
C
C
C
```

```
PAGE  9     SKEW-T PROGRAM ROUTINES
C
C
      FUNCTION  W(T,P)
C     W(GRAMS WATER VAPOR/KILOGRAM DRY AIR ), P(MILLIBAR )
        X  =        ESAT(T)
         W  =  622.*X/(P-X)
      RETURN
         END
C
C
C
C
C
      FUNCTION   O(T,P)
C     O AND T (KELVIN), P (MILLIBARS)
         O =  T*( (1000./P)**.288)
      RETURN
         END
C
C
C
C
C
      FUNCTION   OS(T,P)
C     OS AND T (KELVIN) , P (MILLIBARS )
         OS =    T*((1000./P)**.288 )/( EXP(-2.6518986*W(T,P)/T ) )
      RETURN
         END
```

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